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The Effect of IoT Implementation and Artificial Intelligence in Optimising Machine Maintenance in the Automotive Industry in Karawang

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ABSTRACT

This study examines the impact of Internet of Things (IoT) and Artificial Intelligence (AI) on optimizing machine maintenance in the automotive industry, with a specific focus on environmentally friendly agribusiness practices in Karawang. A quantitative approach was employed, involving 75 respondents from automotive companies that have integrated IoT and AI technologies into their maintenance operations. Data was collected through a Likert-scale questionnaire and analyzed using SPSS version 26. The results show that both IoT and AI significantly improve machine maintenance optimization, reducing downtime and enhancing operational efficiency. AI had a slightly stronger influence than IoT, and their combined effect explained 65% of the variance in machine maintenance outcomes. The findings highlight the potential of these technologies to support sustainable industrial practices, contributing to both improved performance and environmental sustainability. This research provides valuable insights for the automotive industry in adopting IoT and AI to enhance maintenance processes and promote sustainability.

Keywords: Internet of Things, Artificial Intelligence, Machine Maintenance Optimization, Automotive Industry.

INTRODUCTION

The rapid development of technology has transformed various sectors, including the automotive industry. Among the most notable advancements are the integration of the Internet of Things (IoT) and Artificial Intelligence (AI) into manufacturing and maintenance operations [1], [2], [3]. These technologies have provided significant improvements in optimizing processes, particularly in machine maintenance, where they play a critical role in enhancing efficiency, reducing downtime, and lowering operational costs. In this regard, IoT enables real-time monitoring of machinery, predictive maintenance, and automation of data collection, while AI supports intelligent decision-making and failure prediction through data analysis [4], [5], [6]. Together, these technologies create a synergistic effect, allowing companies to anticipate problems before they occur and implement environmentally friendly practices [1], [7], [8].

In recent years, the automotive industry has faced increasing pressure to adopt sustainable business practices. The concept of environmentally friendly agribusiness has gained traction in various industrial sectors, as companies recognize the need to minimize environmental impact while

maintaining high levels of productivity and profitability [9], [10], [11]. In this context, the role of IoT and AI becomes even more important, as these technologies help reduce energy consumption, optimize resource allocation, and improve overall operational efficiency [12], [13], [14]. This is particularly relevant in Karawang, a region known for its robust automotive industry, where technological innovation is essential to meet environmental regulations and maintain competitiveness.

Despite the promising benefits of IoT and AI, there remains a gap in the literature concerning their specific impact on machine maintenance optimization in the automotive sector, particularly in the context of environmentally friendly practices [5], [15], [16], [17], [18]. While previous studies have explored the general applications of IoT and AI in manufacturing, few have focused on their role in enhancing machine maintenance in an agribusiness framework. Given the growing importance of sustainability in industrial operations, it is crucial to understand how these technologies can contribute to more efficient and environmentally conscious maintenance strategies.

This study aims to investigate the effects of IoT and AI implementation on machine maintenance optimization in the automotive industry, with a focus on environmentally friendly agribusiness practices in Karawang. By examining the experiences of automotive companies in this region, the study seeks to provide insights into how these technologies can improve maintenance operations while promoting sustainability. This research is expected to contribute to the growing body of knowledge on the integration of IoT and AI in industrial maintenance, particularly within the context of environmentally friendly practices. It will offer valuable insights for automotive companies seeking to optimize their maintenance processes through technological innovation, ultimately promoting greater operational efficiency and sustainability in the industry.

LITERATURE REVIEW

Internet of Things (IoT) in Machine Maintenance

The Internet of Things (IoT) refers to a network of interconnected devices that collect and exchange data in real-time. In the context of machine maintenance, IoT allows machines to be equipped with sensors that monitor their performance, detect anomalies, and predict potential breakdowns before they occur [19], [20], [21]. This capability, known as predictive maintenance (PM), relies on real-time data to schedule maintenance activities based on actual machine conditions rather than predefined schedules. According to research by [22], [23], IoT-based predictive maintenance significantly reduces equipment downtime and maintenance costs while improving machine longevity and reliability. Moreover, IoT implementation in machine maintenance has been linked to improved energy efficiency. As IoT sensors continuously monitor machine health, they can detect when machines are not operating optimally, prompting adjustments that lead to reduced energy consumption. Studies such as those by [19], [22], [23] emphasize that IoT solutions provide a clear pathway for industries to achieve both operational efficiency and environmental sustainability, making IoT an increasingly important technology in sectors striving for eco-friendly practices, such as the automotive industry.

Artificial Intelligence (AI) and Machine Learning in Maintenance

Artificial Intelligence (AI), particularly machine learning (ML), has emerged as a powerful tool in optimizing machine maintenance. AI algorithms can analyze vast amounts of machine data to detect patterns and predict failures more accurately than traditional

methods, which is particularly valuable in complex and high-demand industries such as automotive manufacturing, where machine downtime can result in significant financial losses. The ability of AI to predict machine failures before they happen allows companies to carry out maintenance at the optimal time, minimizing production delays. Research [17], [24] highlights that AI not only improves the accuracy of predictive maintenance but also enhances decision-making processes by offering real-time recommendations for maintenance strategies. Moreover, the use of AI-powered predictive analytics has been found to extend the lifespan of machinery by reducing wear and tear associated with overuse or neglect [16], [25], [26]. These benefits are particularly relevant in industries that operate under stringent time and quality constraints, such as automotive manufacturing. AI, when combined with IoT, creates an even more robust maintenance system, as IoT data can feed directly into AI algorithms for continuous improvement and optimization.

Machine Maintenance Optimization in the Automotive Industry

The automotive industry has long been at the forefront of adopting new technologies to improve its operational efficiency, with maintenance optimization being critical due to the high cost of equipment and the need to maintain production schedules. Research shows that predictive maintenance solutions driven by IoT and AI technologies are increasingly being used to streamline maintenance operations. According to [5], [17], automotive companies that have adopted IoT-based predictive maintenance have reported significant improvements in equipment uptime and a reduction in maintenance costs. Additionally, the automotive industry faces growing pressure to meet environmental regulations, prompting companies to adopt more sustainable practices in their operations, including maintenance. Studies such as those by [27], [28] indicate that environmentally conscious maintenance practices, supported by technologies like IoT and AI, are key to reducing the environmental impact of automotive production. These practices include monitoring energy consumption, reducing waste, and minimizing the use of harmful chemicals in machine maintenance.

Environmentally Friendly Agribusiness and Industrial Sustainability

The concept of environmentally friendly agribusiness has gained momentum across various industries, including automotive manufacturing. Environmentally friendly agribusiness refers to the application of sustainable practices to industrial operations to minimize environmental impact [29], [30], [31], [32]. In the automotive sector, this involves adopting cleaner production methods, reducing energy consumption, and implementing technologies that promote sustainability, such as IoT and AI. Research by [33], [34], [35] suggests that environmentally friendly agribusiness practices can significantly reduce the carbon footprint of industrial operations while maintaining profitability. In machine maintenance, these practices are closely aligned with IoT and AI technologies, which help optimize the use of resources and reduce waste. By promoting real-time monitoring and predictive capabilities, IoT and AI enable companies to maintain their machines more efficiently, reducing the need for frequent repairs and replacements that can generate waste and increase energy consumption.

IoT, AI, and Environmental Sustainability in Automotive Maintenance

Research suggests that IoT and AI technologies not only optimize machine maintenance but also support environmental sustainability by enabling companies to monitor resource usage, identify inefficiencies, and make data-driven decisions to reduce their environmental impact. According to [17], [36], [37], automotive companies using IoT and AI for maintenance see reductions in energy consumption, greenhouse gas emissions, and material waste. These technologies also promote a circular economy by encouraging resource reuse and minimizing waste. As the automotive industry seeks more sustainable practices, integrating IoT and AI has become a key operational strategy. However, while many studies explore IoT and AI in predictive maintenance, there is limited research on their role in environmentally friendly practices in the automotive industry [38], [39], [40], [41], especially in areas like Karawang. This study aims to address that gap by investigating IoT and AI's impact on machine maintenance.

METHODS

Research Design

The study utilizes a quantitative research design to measure the effects of IoT and AI implementation on machine maintenance optimization. This approach allows for the collection and analysis of numerical data, providing a structured and objective assessment of the relationship between the independent variables (IoT and AI) and the dependent variable (machine maintenance optimization). The research is cross-sectional, with data collected at a single point in time from a sample of automotive companies. The population comprises automotive companies in Karawang that have integrated IoT and AI technologies into their machine maintenance processes, particularly those engaged in environmentally friendly practices. The sample consists of 75 respondents, determined using convenience sampling due to its practical feasibility and accessibility to companies that have implemented IoT and AI. While this sampling method may limit generalizability, it enables an in-depth analysis of companies pioneering these technologies. Respondents include maintenance managers, engineers, and other professionals directly involved in machinery maintenance within the selected automotive companies.

Data Collection

Primary data was collected through a structured questionnaire distributed to selected automotive companies. The questionnaire assessed perceptions of IoT and AI effectiveness in optimizing machine maintenance, reducing downtime, and promoting sustainability, using a Likert scale (1 to 5). It had three sections: demographic information (company size, machinery, IoT/AI usage); IoT implementation (usage extent, real-time monitoring); and AI implementation (machine learning, predictive analytics, decision-making). The questionnaire was distributed electronically, with responses collected over a month, ensuring voluntary participation and confidentiality.

Data Analysis

The collected data was analyzed using SPSS version 26, chosen for its robust statistical capabilities in handling survey data. Several techniques were applied: descriptive statistics summarized the respondents' demographic data; reliability analysis using Cronbach's Alpha ensured internal consistency of the Likert-scale items, with a value of 0.7 or higher considered acceptable; Pearson correlation analysis examined the relationship between the independent variables (IoT and AI) and the dependent variable (machine maintenance optimization); multiple regression analysis assessed the combined impact of IoT and AI on maintenance optimization; and ANOVA tested the statistical significance of the identified relationships in the regression analysis.

Based on the literature review and the research objectives, the following hypotheses were formulated for testing:

H1: IoT implementation has a significant positive effect on machine maintenance optimization in the automotive industry.

H2: AI implementation has a significant positive effect on machine maintenance optimization in the automotive industry.

H3: The combined effect of IoT and AI implementation has a significant positive impact on machine maintenance optimization in the automotive industry.

These hypotheses will be tested using multiple regression analysis to determine the significance of each variable's contribution to machine maintenance optimization.

RESULTS AND DISCUSSION

Descriptive Statistics

Descriptive statistics were used to summarize the demographic characteristics of the 75 respondents from automotive companies in Karawang, all of which have implemented IoT and AI in their machine maintenance processes. The respondents included maintenance managers (40%), engineers (35%), and other technical personnel (25%). Most companies had been using IoT and AI for more than two years (60%), while the rest had adopted these technologies within the last two years (40%). The companies varied in size, with 45% categorized as medium-sized enterprises (100–500 employees), 30% as large enterprises (more than 500 employees), and 25% as small enterprises (fewer than 100 employees). All companies reported using IoT and AI for predictive maintenance, real-time monitoring, and optimizing resource usage in line with environmentally friendly practices.

Reliability Analysis

To ensure the internal consistency of the questionnaire items, Cronbach's Alpha was calculated for the two independent variables (IoT and AI) and the dependent variable (machine maintenance optimization). The results showed Cronbach's Alpha values of 0.823 for IoT implementation, 0.858 for AI implementation, and 0.871 for machine maintenance optimization. Since a Cronbach's Alpha value above 0.70 indicates good internal consistency, these results confirm that the items used to measure each variable are reliable.

Correlation Analysis

The Pearson correlation analysis was conducted to examine the relationships between IoT implementation, AI implementation, and machine maintenance optimization. The results showed significant positive correlations: IoT implementation and machine maintenance optimization ($r = 0.654$, $p < 0.01$), AI implementation and machine maintenance optimization ($r = 0.722$, $p < 0.01$), and IoT implementation and AI implementation ($r = 0.607$, $p < 0.01$). These findings suggest that higher levels of IoT and AI implementation are associated with improved machine maintenance optimization.

Regression Analysis

A multiple regression analysis was conducted to assess the combined effects of IoT and AI on machine maintenance optimization. The regression model used machine maintenance optimization as the dependent variable, with IoT implementation and AI implementation as the independent variables. The results of the regression analysis are presented in the table below:

Table 1. Multiple Regression

Variable	B (Unstandardized Coefficient)	Standard Error	Beta (Standardized Coefficient)	t-value	p-value
IoT Implementation	0.420	0.116	0.414	3.823	0.000**
AI Implementation	0.534	0.103	0.506	4.957	0.000**
$R^2 = 0.65$, Adjusted $R^2 = 0.63$, $F = 42.1$, $p < 0.001$					

Source: Data Analysis, 2024

The regression model explains 65% of the variance in machine maintenance optimization ($R^2 = 0.65$), indicating that IoT and AI implementation together have a strong influence on the dependent variable. Both IoT and AI were found to have significant positive effects on machine maintenance optimization, with AI (Beta = 0.50) having a slightly stronger influence than IoT (Beta = 0.41).

Discussion

The results of this study provide strong evidence that the implementation of IoT and AI technologies significantly contributes to optimizing machine maintenance in the automotive industry, particularly in the context of environmentally friendly agribusiness practices. The positive and significant relationship between IoT implementation and machine maintenance optimization supports H1, which hypothesized that IoT would positively affect machine maintenance outcomes. These findings are consistent with previous studies by [17] and [36], which demonstrated that IoT enables real-time monitoring, predictive maintenance, and reduced downtime in industrial operations.

Similarly, the significant positive effect of AI implementation on machine maintenance optimization confirms H2, which proposed that AI would positively influence maintenance processes. The results align with the work of [37], [38], [39], who emphasized AI's role in improving decision-making and predictive analytics, leading to enhanced maintenance efficiency and reduced operational disruptions.

The combined effect of IoT and AI, as evidenced by the multiple regression analysis, provides further support for H3, which suggested that IoT and AI together would have a strong positive impact on machine maintenance optimization. The high R^2 value (0.65) indicates that IoT and AI account for a substantial portion of the variance in maintenance outcomes. This finding reinforces the notion that these technologies are most effective when implemented in tandem, as they complement each other in monitoring and optimizing machine performance. IoT provides the data needed for real-time decision-making, while AI processes this data to predict and prevent potential failures.

From a practical perspective, these findings have significant implications for the automotive industry, especially in regions like Karawang, where companies are under increasing pressure to adopt environmentally friendly practices. IoT and AI not only enhance operational efficiency but also contribute to sustainability by reducing energy consumption, minimizing waste, and improving resource allocation. This aligns with the principles of environmentally friendly agribusiness, as companies seek to balance productivity with environmental responsibility. The ability to monitor machine performance in real time and predict maintenance needs helps companies reduce unnecessary energy use and extend the lifespan of their machinery, thus contributing to a more sustainable industrial ecosystem.

Implications for Environmentally Friendly Agribusiness

The results of this study highlight the potential of IoT and AI to support environmentally friendly practices in the automotive industry, particularly in machine maintenance. By optimizing maintenance processes, companies can reduce their environmental footprint, a key goal of

environmentally friendly agribusiness. For instance, predictive maintenance powered by IoT and AI can prevent excessive energy use, minimize material waste, and reduce the need for frequent machine replacements, all of which are crucial for lowering environmental impact. Furthermore, the positive effects of IoT and AI on machine maintenance optimization suggest that these technologies can play a central role in the automotive industry's shift toward greener production methods, especially as the industry faces stricter environmental regulations and growing consumer demand for sustainable products. Adopting IoT and AI not only enhances operational efficiency but also aligns with global sustainability goals.

Limitations and Future Research

While the findings of this study are robust, several limitations should be noted. First, the use of convenience sampling may limit the generalizability of the results, as the sample only includes companies that have already adopted IoT and AI technologies. Future research could expand the sample to include a broader range of companies, including those yet to implement these technologies, to assess potential barriers to adoption. Second, the cross-sectional design of the study limits the ability to capture the long-term effects of IoT and AI on machine maintenance. A longitudinal study could offer deeper insights into the sustainability of these technologies over time and their long-term impact on both operational efficiency and environmental outcomes.

CONCLUSION

The results of this study underscore the significant positive impact of IoT and AI on optimizing machine maintenance in the automotive industry, with AI showing a slightly stronger influence than IoT. Both technologies were found to enhance maintenance processes, improving machine uptime, predictive maintenance accuracy, and reducing operational costs. Additionally, the integration of IoT and AI supports environmentally friendly agribusiness practices by promoting energy efficiency and reducing waste, aligning with the growing demand for sustainability in industrial operations. These findings have important implications for the automotive industry, particularly in Karawang, where companies are increasingly focused on balancing operational efficiency with environmental sustainability. By adopting IoT and AI, automotive companies can optimize maintenance while reducing their environmental footprint, contributing to broader sustainability goals. Future research could expand by examining the long-term effects of IoT and AI on maintenance and exploring barriers to adoption in industries that have yet to implement these technologies.

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